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M4Or1B-06: Design and cryogenic mechanics finite element analysis of a novel sandwich structure mouth for Type V storage vessels

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Liquid hydrogen (LH2), recognized as a sustainable green fuel, has garnered significant attention in the field of unmanned aerial vehicles (UAVs) owing to its high energy density and hydrogen purity. However, storing LH2 imposes stringent requirements on the cryogenic temperature mechanical properties of hydrogen storage vessels. Existing hydrogen storage vessels are susceptible to inner liner failure at cryogenic temperatures due to the thermodynamic mismatch between the liner material and the external carbon fiber reinforced polymer (CFRP). In response, a linerless hydrogen storage vessel (Type V vessel) has been proposed as a potential solution. However, the thermal mismatch between the metal material of the BOSS structure and CFRP at cryogenic temperatures presents a significant challenge to the further development of the Type V vessel.
This study employs CFRP with added polyethylene (PE/CFRP) as the inner layer for the Type V vessel. A CFRP-BOSS-PE/CFRP sandwich structure is proposed to mitigate the thermal mismatch between the BOSS structure and the carbon fiber composite at cryogenic temperatures. The sandwich structure consists of a CFRP outer layer, a 6061-T6 aluminum alloy BOSS intermediate layer, and a PE/CFRP inner layer, with adhesive bonding facilitated by a 7 wt.% polyethylene glycol (PEG)-modified polyurethane (PU) resin. The dome of the PE/CFRP liner is designed with a standard ellipsoidal profile. The inner surface of the BOSS is shaped to conform to the ellipsoidal profile of the PE/CFRP liner, with its maximum inner diameter equal to half the outer diameter of the PE/CFRP liner. The outer surface of the BOSS is also designed with an ellipsoidal profile. The CFRP layer is tailored to match the shape of the BOSS structure.
A finite element model of the sandwich structure for cryogenic mechanics was developed to assess the structural reliability under LH2 storage conditions. Based on a PE/CFRP liner with a body length of 390 mm, an outer diameter of 160 mm, and an ellipsoidal head ratio of 2, BOSS structures with outer surface ellipsoidal ratios of 1.2, 1.3, 1.4, 1.5, and 1.6 were designed. Using these structures, 1/8-scale finite element models of the Type V vessels were developed. Cohesive zone model was employed to simulate the bonding between the different material layers. Static structural simulations were conducted on these models under LH2 storage conditions (20 K, 2 MPa). The simulation results demonstrate that the interface stress in all models remains below 60 MPa, which is within the elastic limit of the modified PU resin at the specified temperature. These results confirm that the adhesive material in all models remains within the elastic phase. The BOSS with an outer surface ellipsoidal ratio of 1.4 exhibited the lowest maximum interface stress, thereby making it the optimal design.
Therefore, the proposed CFRP-BOSS-PE/CFRP sandwich structure represents a viable design for Type V vessels. The BOSS with an outer surface ellipsoidal ratio of 1.4 demonstrates optimal mechanical performance under LH2 storage conditions. The vessel mouth sandwich structure and BOSS design offer significant potential for application in the manufacturing of Type V LH2 storage vessels.

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